Southern Root-Knot Nematode (*Meloidogyne incognita*) Affects Common Cocklebur (*Xanthium strumarium*) Interference with Cotton

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Southern root-knot nematode and common cocklebur interfere with cotton growth and yield. A greater understanding of the interaction of these pests with cotton growth and yield is needed for effective integrated pest management (IPM). An additive design was used in outdoor microplots with five common cocklebur densities (0, 1, 2, 4, and 8 plants per plot) growing in competition with cotton, with and without the presence of southern root-knot nematode. Differences in cotton height could not be detected among common cocklebur densities or nematode presence at 3 wk after transplanting (WAT); however, differences in crop height were observed at 5 WAT between nematode treatments. In the absence of nematodes, the relationship between cotton yield loss and common cocklebur density was described by a rectangular hyperbolic regression model (P < 0.0001). Maximum yield loss from common cocklebur in the absence of nematodes exceeded 80%. In the presence of nematodes, there was a linear relationship between cotton yield loss and common cocklebur density (P = 0.0506). The presence of nematodes at each common cocklebur density increased cotton yield loss 15 to 35%. Common cocklebur plant biomass was 25% greater in nematode treatments, likely because of the reduced competitiveness of the cotton plants in these plots. This study demonstrates that multiple pests can interact to cause an additive reduction in crop yield.

Nomenclature: Common cocklebur, *Xanthium strumarium* L. XANST; cotton, *Gossipium hirsutum* L.; southern root-knot nematode, *Meloidogyne incognita* Kofoid & White (chitwood), host race 3.

Key words: Integrated pest management, multiple pests, pest complex, plant-parasitic nematode.

Common cocklebur was among the 10 most common cotton weeds in Alabama, Florida, Georgia, Missouri, Mississippi, North Carolina, Oklahoma, South Carolina, and Tennessee when surveyed by Webster (2001). At high common cocklebur densities (6.6 plants m^{-1} of cotton row), which reflected both interspecific interference of common cocklebur with cotton as well as intraspecific common cocklebur interference, Buchanan and Burns (1971) found that cotton yield loss was 80%. In a study by Byrd and Coble (1991), common cocklebur densities of 0.48 plants m^{-1} of cotton row reduced cotton yield 31%. At lower common cocklebur densities, cotton yield loss ranged between 3 and 10% at densities of 0.066 common cocklebur plants m^{-1} of crop row (Snipes et al. 1982), and likely only represented interspecific interference. The robust growth of common cocklebur both within and above a crop canopy contributes to its weedy nature (Regnier and Harrison 1993).

Nematodes are the most damaging pathogens of cotton, costing an estimated $6.7 billion in losses the United States in 1994 (Koenning et al. 1999). The most damaging nematode in cotton production in the United States is southern root-knot nematode, which, in a study by Davis and May (2005), caused up to 47% cotton yield loss. In Georgia, southern root-knot nematode infests 60 to 70% of the hectares planted in cotton, with medium to high populations occurring in over half of the cotton-growing counties (Shurley and Kemerait 2005).

Independently, weeds and nematodes cause significant crop yield losses. Studies have documented that weeds can serve as a reservoir for nematode populations (Belair and Benoit 1996; Davidson and Townshend 1967; Davis and Webster 2005; Ehwaeti et al. 1999; Queneherve et al. 2006; Robbins et al. 1990; Wong and Tylka 1994). Differential sensitivity of weeds and crops to nematode damage may pose significant

economic challenges for growers, especially when considering that there are no cotton cultivars commercially available with a high level of resistance to southern root-knot nematode (Davis and May 2005). Previous research has demonstrated that nematodes can affect the ability of weeds to cause crop yield loss (Alston et al. 1991a, 1991b; Koenning et al. 1998; Pantone 1995; Ponce et al. 1995; Thomas et al. 1997; Venkatesh et al. 2000; Zancada et al. 1998). However, potential interactions between weeds and nematodes and their effect on cotton growth and yield have not been evaluated. Effective IPM strategies need to address both weeds and nematodes collectively (Thomas et al. 2005). The objective of this study was to evaluate the hypothesis that nematodes will intensify crop yield loss due to weed interference.

Materials and Methods

Studies were conducted in 2004 and 2005 at the University of Georgia, Tifton Campus. Microplots consisted of 76-cm-diam bottomless steel drums that were countersunk so that approximately 7 cm of the barrels were above the soil surface and 53 cm below the soil surface. The soil was a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 86% sand, 7% silt, and 7% clay (Perkins et al. 1986). Cotton 'FM989RR' was planted in the greenhouse on May 7, 2004, and April 26, 2005, in trays containing 4-cm by 4-cm cells.

Eight cotton plants with one to two true leaves were transplanted into the microplots on May 21, 2004, and May 10, 2005, in a single row with 10 cm between each plant. Common cocklebur plants with one true leaf, from a naturalized population in Tifton, were transplanted the same day as cotton. Treatments consisted of an additive design of common cocklebur densities that included 0, 1, 2, 4, and 8 plants per plot that were transplanted 5 cm offset from the cotton row and spaced in between cotton plants. The study was arranged as a randomized complete block design and each treatment was replicated five times.

Table 1. Cotton and common cocklebur growth characteristics in nematode inoculated and noninoculated treatments combined over both years and common cocklebur densities.[a]

Nematode level	Cotton plant height		Cotton plant width		Common cocklebur biomass	Cotton root gall rating[b]
	3 WAT	5 WAT	3 WAT	5 WAT		
	————————————————— cm —————————————————				kg	
Inoculated	11.2 A	17.3 B	8.7 A	12.5 B	1.6 A	9.1 A
Noninoculated	11.6 A	24.8 A	9.1 A	18.8 A	1.3 B	0.4 B

[a] Means within a column followed by the same letter are not statistically different according to Fisher's Protected LSD at an alpha level of 0.05.
[b] Based on a scale of 0 to 10, with 0 = no galling, 1 = 1 to 10% of the root system galled, 2 = 11 to 20% of the root system galled, etc., with 10 = 91 to 100% of the root system galled.

Southern root-knot nematodes were added to half of the microplots in 2004. In the greenhouse, 2-wk-old tomato plants (Lycopersicon esculentum 'Rutgers') were transplanted into 15-cm-diam pots containing 2,700 cm^3 soil, and inoculated with 8,000 eggs of southern root-knot nematode (race 3) 1 wk after transplanting. On May 17, 2004, 8 wk after inoculation, soil and intact tomato roots from one pot were added to each microplot designated for infestation and thoroughly mixed in using a shovel to a depth of approximately 25 cm. Inoculum applied this way would not have been identical for each microplot, but was estimated to have averaged 1,000,000 eggs and vermiform nematodes per microplot. On May 25, 2004 (4 d after transplanting cotton and common cocklebur), nematode eggs were added as supplemental inoculum to each infested microplot. Eggs were extracted from tomato roots by agitating roots in 0.5% sodium hypochlorite solution for 2 min (Hussey and Barker 1973) approximately 1 hr before inoculation. Inocula of 40,000 eggs microplot^{-1} were evenly distributed into seven holes (approximately 2.5 cm deep) in each microplot, one at the base of each cotton plant, and covered with soil. Microplots were watered immediately following inoculation. Inoculum was not added in 2005; plots inoculated in 2004 were used as nematode-present plots in 2005 and weed densities were rerandomized.

Soil samples for nematode analysis were collected from the microplots on July 8 and October 4, 2004, and May 19, July 29, September 7, and October 28, 2005. Soil samples consisted of a composite of eight cores per microplot (2.5 cm diam and approximately 20 cm deep, four cores from each side of the row) collected from the root zone. Nematodes were extracted from 150 cm^3 soil by centrifugal flotation (Jenkins 1964). Measurements of crop height and canopy width were recorded at 3 and 5 WAT.

Cotton was harvested by hand on October 1, 2004. In 2005, cotton was harvested throughout a 2-wk period which ended on November 3. Root galling was evaluated on a 0 to 10 scale on October 14, 2004, and November 3, 2005, by digging and rating all cotton root systems in each microplot. The scale used ranged from 0 to 10: 0 = no galling, 1 = 1 to 10% of the root system galled, 2 = 11 to 20% of the roots system galled, etc., with 10 = 91 to 100% of the root system galled.

Data were subjected to ANOVA. There were no significant treatment-by-year interactions; therefore data were combined over years. There was a significant nematode-by-weed interaction for cotton yield. Cotton yield loss, expressed as a percentage of the noninoculated weed-free control, was regressed on common cocklebur density. For nonnematode treatments, the relationship between cotton yield loss and common cocklebur data was described by a rectangular

hyperbolic regression model (Cousens 1991). A linear regression model was fit to all of the data for the nematode-inoculated treatments, with treatment means presented for clarity.

Results and Discussion

Differences in cotton height and canopy width could not be detected among common cocklebur densities or nematode presence at 3 WAT, so results were combined over density treatments (Table 1). Common cocklebur density did not affect cotton growth at 5 WAT (data not shown). Previous studies indicated there was no clear relationship between vegetative cotton growth and yield loss due to common cocklebur interference (Buchanan and Burns 1971; Byrd and Coble 1991). However, differences in crop growth between nematode treatments were observed at 5 WAT. Cotton plant height (24.8 cm) in the absence of nematodes was 43% larger than in treatments with nematodes (17.3 cm) (Table 1). The width of the cotton canopy was also reduced 33% when nematodes were present (12.5 cm) relative to nematode-free plots (18.8 cm). Cotton plant volume, composed of both canopy width and plant height, in the nematode-infested plots was less than one-third (2,123 cm^3) of that in the nematode-free plots (6,884 cm^3). These findings are in contrast with research on the interactions among soybean cyst nematode (Heterodera glycines Ichinohe), common lambsquarters (Chenopodium album L.), and soybean [Glycine max (L.) Merr.] yield loss in which early-season weed interference on crop growth was detected, but nematode impact was not measured until later in the season (Chen et al. 1995). However, Chen et al. (1995) inoculated microplots following soybean transplanting, whereas in the current study the nematodes were added on tomato roots several days before cotton was transplanted. Also, Chen et al. (1995) inoculated each microplot with approximately 15,000 eggs and second-stage juveniles, whereas nearly 1,000,000 eggs and vermiform nematodes were added to each microplot in the current study, which may have contributed to more rapid nematode colonization of the cotton roots.

Not only was cotton growth affected by nematodes, but common cocklebur growth was indirectly affected. When averaged across all weed densities at the conclusion of the growing season, common cocklebur biomass was 25% larger in treatments that were inoculated with nematodes (1.64 kg) relative to those that were not inoculated (1.31 kg). Previous research indicated that common cocklebur was a poor host for southern root-knot nematode (Davis and Webster 2005; Tedford and Fortnum 1988). The difference in growth between nematode-free and nematode-infested treatments is

Table 2. Nematode soil population density as affected by common cocklebur density.

Common cocklebur density (plants plot^{-1})	September 2005	October 2004 and 2005
	Nematode population density (nematodes cm^{-3})[a]	
0	375 A	734 A
1	56 B	398 A–C
2	76 B	661 A,B
4	56 B	339 B,C
8	42 B	237 C

[a] Nematode soil population density was sampled in September 2005 and October 2004 and 2005. Means within a column followed by the same letter are not statistically different according to Fisher's Protected LSD at an alpha level of 0.05.

Figure 1. The relationship between common cocklebur density and cotton yield loss in both the presence and absence of southern root-knot nematodes.

likely attributed to increased cotton plant growth and competitiveness with common cocklebur in the absence of nematodes.

Nematode soil population densities were affected by the presence of common cocklebur (Table 2). In September 2005, nematode soil population densities in common cocklebur treatments were approximately one-fifth of that in the common cocklebur-free treatment. The degree of nematode infection of roots is related to plant growth. Interference from common cocklebur reduced cotton growth and yield (Figure 1). The same trend observed in September 2005 was present in October averaged over both years. The highest common cocklebur densities in October had lower nematode soil population densities than did the common cocklebur–free treatments. These results are consistent with previous research; soybean interference with a nonhost weed had lower levels of soybean cyst nematodes relative to soybeans growing without weed interference (Alston et al. 1993). Because of the high inoculation levels in the current study, treatment differences among common cocklebur densities for cotton root galling were not detectable.

In the absence of nematodes, the relationship between cotton yield loss and common cocklebur density was described by a rectangular hyperbolic regression model (P < 0.0001). Maximum yield loss from eight common cocklebur per plot (10.5 common cocklebur plants m^{-1} of row), in the absence of nematodes, was 83% in these microplots (Figure 1). This is consistent with previous small-plot research in which 6.6 common cocklebur plants m^{-1} of row reduced cotton yield by 80% (Buchanan and Burns 1971). In the current study, the lowest density tested (1.32 plants m^{-1} of row) reduced cotton yield by 60%. Snipes et al. (1982) found a 65 and 70% yield loss for common cocklebur densities of 1.07 and 2.13 plants m^{-1} of row, respectively.

In the presence of nematodes, there was an approximate linear relationship between cotton yield loss and common cocklebur density (P = 0.0506). In the absence of common cocklebur, nematode presence alone reduced cotton yield 82% relative to the noninoculated weed-free control. The presence of nematodes added 15 to 35% cotton yield loss at each common cocklebur density, to a maximum yield loss of 98% at the highest weed density (Figure 1).

Common cocklebur is a very competitive weed species in several different crops (Neary and Majek 1990; Patterson and Flint 1983; Regnier and Stoller 1989; Royal et al. 1997; Stoller et al. 1987). Competition for water and light between common cocklebur and cotton are likely among the most important factors contributing to cotton yield loss. Previous studies have found that common cocklebur roots grew to
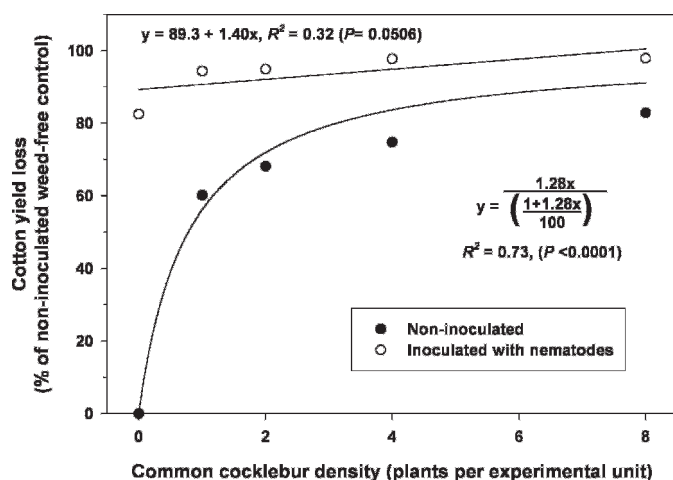
a depth of 2 m, whereas cotton roots grew to only 1 m (Wells et al. 1984), which may make common cocklebur a more effective competitor for water. Susceptibility of cotton to nematode infection will limit root growth, putting the crop at an even greater disadvantage in terms of competition for water. Previous research determined that common cocklebur accumulated more leaf area and biomass than cotton (Byrd and Coble 1991), which reflects its ability to harvest the limited resources (e.g., light and water) better than cotton.

Because of the size of the microplots (0.76 m of cotton row), the ability to include a range of common cocklebur densities was limited. The common cocklebur densities in this study likely represented the second linear component of the rectangular hyperbolic response, which includes both interspecific and intraspecific interference. This study demonstrated that multiple pests interacted to cause a reduction in crop yield, and that the effect of the multiple pests was additive. Previous research indicated that different pests will cause an additive, and not synergistic, crop yield loss (Chen et al. 1995; Robbins et al. 1990; Zancada et al. 1998). Common lambsquarters and soybean cyst nematode acted independently in reducing soybean yield (Chen et al. 1995). Although sensitive to southern root-knot nematode, black nightshade (*Solanum nigrum* L.) growth was less affected by the nematode than was the growth of bell pepper (*Capsicum annuum* L.) (Zancada et al. 1998). The combination of black nightshade and southern root-knot nematode infestation was additive on bell pepper yield reduction. A three-way interaction among soybean, soybean cyst nematode, and corn earworm (*Helicoverpa zea* Boddie) was found to be additive (Alston et al. 1993). Interactions among three types of pest organisms, weeds (common cocklebur, pitted morningglory [*Ipomoea lacunosa* L.], and sicklepod [*Senna obtusifolia* (L.) Irwin and Barneby]), an insect (threecornered alfalfa hopper [*Spissistilus festinus* Say]), and soybean cyst nematode were found to be additive in their ability to reduce soybean yield loss (Robbins et al. 1990).

Effective IPM in cotton will require that pests and their interactions are accounted for when making management decisions to optimize crop growth. With limited nematicide options, non–host-crop rotation is a critical component of a nematode management plan (Thomas et al. 2005). The presence of nematode-susceptible weeds will have negative

consequences in terms of nematode populations during the non–host-crop portion of the rotation (Davis et al. 2006). However, Thomas et al. (2005) suggested that weed-nematode interactions in cropping systems may go beyond simply weeds serving as alternate hosts for nematodes. The current research supports this contention, as common cocklebur and southern root-knot nematode caused an additive reduction in cotton yield that was greater than the cotton yield loss from either pest in isolation. Circumstances in which both crop and weeds are susceptible hosts to nematode species present unpredictable interactions that may influence the estimation of crop yield loss attributed to these pests. It is also not known how a nematode-susceptible weed and a nematode-resistant crop or nonhost crop will affect weed interference with crop growth and yield. Greater understanding of these interactions will improve the efficiency of IPM.

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